CHAPTER II

LITERATURE REVIEW

This chapter is devoted for not only review of some previous representative reports about development of the transparent alumina ceramic using various methodologies, but also survey of information of processing factors effect on optical properties of alumina ceramic.

2.1 Development of transparent alumina ceramic

R. Apetz et al. (2003) proposed a model for elucidating causes of translucency and transparency of alumina ceramic by using the light scattering model based on Rayleigh-Gans-Debye light scattering theory. Light scattering at rough surface, at second phase inclusion, at grain boundaries, and at pores are the possible is indicated as causes of for nontransparency of materials. The first two scatterings are eradicated by making its surface smooth (polishing the surface) and using alumina powder with high purity(>99%). On the other hand, the latter two scatterings cannot be avoided. They can be minimized by reducing size of the alumina sintered body due to in-line transmission influence.

Y. Hotta et al. (2000) employed slip casting to develop translucent alumina ceramic using acid treatment technique. This technique uses 0.9N HCl solution for removing $CaSO_4$ impurity which had penetrate into the alumina green body prepared from 70 % and 80% content of well-dispersed alumina slurries. They found that not only Ca^{2+} could be removed but it also helped give the homogeneous growth of grains and higher relative density after sintering for 2 h under vacuum. Moreover, the transmittance of HCl treatment sample increased from 0% to 12% as wavelength increased from 300-900 nm. Whereas, untreated specimens were not translucent.

Y. Hotta et al. (2002) investigated further on acid treatment of translucent alumina in order to confirm the efficiency of the acid treatment in the changing of microstructure by varying the type of alumina powder and sintering temperature. They found that acid treatment could decrease grain size in the range of 0.2-2, 3-7, and 5-10μm at 1350 ^{o}C, 1450 ^{o}C and 1550 ^{o}C for specimens prepared from 80 % solid loading slurries, respectively.

Y. Hotta et al. (2003) investigated the effect of adding oligosaccharide alcohol in alumina slurry and sintered alumina ceramic (consisting of high-purity alumina powder with submicrometer size, ammonium salt of polymethacrylic acid as deflocculant) on slurry viscosity and dispersibility, and transmittance of ceramic specimen, respectively. They found that adding oligosaccharide alcohol to alumina slurry with ammonium salt of polymethacrylic resulted in lower viscosity and better dispersibility of high solid loading slurry which give rise to the sintered alumina sample with light transmission slightly higher than that of sample without adding alcohol.

Y.T. O et al. (2004) investigated the effect of average grain size on the transmittance and mechanic strength of sintered α-Al_2O_3. They found that the sintered alumina did not show transmittance when the average grain size was between 2 μm and 7μm. This could be implied as a result of Mie scattering phenomenon. The transmittance is slightly increased to 30% when the grain size become larger than or equal to 7μm. On the other hand, the transmittance is immediately increased more than or equal to 50% when the grain size was reduced from 2 μm to 0.8 μm. This could be explained by Rayleigh scattering theory. In addition, they found that decrease of grain size results in improvement of sintered body strength.

A. Krell et al. (2003) employed commercial alumina powder (particle size about 0.2 μm) doped with small amount of impurity such MgO and ZrO_2 for inhibition of abnormal grain growth, and a wet-shaping process for producing transparent alumina product such complex hollow shape and large flat windows. They

also investigate the effect of dopants, compaction process, sintering condition and hot isostatic pressure(HIP) condition on the properties of their product until obtaining the transparent alumina with the desire properties as follow;

1. Grain size is about 0.4- 0.6μm at >99.9% relative density

2. Hardness is 20-21 GPa, which enables the development of scratch-resistant widows and transparent Alumina armor.

3. Strength is 600-700 MPa in four-point bending (750-900 MPa in three-point bending) at a Weibull modulus up to 15

4. Real in-line transmission is 60% (at 0.8 mm thickness, with lapped surfaces and at $\lambda = 650$ nm).

D. Goglinski et al. (2002) proposed the new route for preparing the material such a transparent alumina by sedimentation technique. The stabilization of alumina suspension, consolidation and drying step were controlled in order to give homogeneous green body which was sintered at 1275 ^{o}C in air to give transparent product. They also conducted the experiment to compare the transparency of their product with the other technique such pressure filtration.

C. Scott et al. (2002) employed the solid-state crystal conversion technique for producing the transparent alumina by converting the polycrystalline ceramics into the single crystal via abnormal grain growth behavior. They found that more than 30-40% of polycrystalline Mg-O doped alumina tube can be converted to sapphire crystal at 1880 ^{o}C in H_2 gas via this method

J. Cheng et al. (2002) employed microwave sintering technique for producing the transparent alumina. They found that this technique use lower temperature and shorter sintering time to give the fully dense alumina compared with the conventional sintering process. Moreover, this technique also could increase the conversion rate of polycrystalline alumina to single crystal alumina.

G. C. Wei et al. (2001) developed the translucent alumina tube for high-pressure sodium lamp using the composition of alumina with dopants. Due to the reaction of polycrystalline alumina with sodium causes alumina decomposition into aluminum which is depositing on, darkening the surface of the tube and reducing the light output, some cations are added to improve the sodium resistance. MgO is also one of componens require for making the translucent alumina tube for sodium lamp. MgO is distributed in polycrystalline by dissolving in the alumina lattice, by segregation at the grain boundaries and by forming spinel ($MgAl_2O_4$) phase or other second phase. From the previous experiment, they found that Sodium preferentially reacted with spinel second phase to form β-Al_2O_3, so improving of the sodium attack is proposed by using appropriated content of MgO in dopant formulation, doping with tetratvalent cations to charge-compensate for Mg^{2+} at alumina lattice site, and/or forming a second phase to absorb supersaturated MgO in situ.

M. Shimada et al. (1996) developed the transparent polycrystalline material of the spinel-alumina solid solution by reaction sintering using spinel, magnesia and alumina as starting materials. They fabricated the mixed powders by isostatic pressing to pellet, and sintered in air at 1450-1550 ^{o}C for -16 h followed by hot isostatic pressing at 1600-1800 ^{o}C and 150 MPa in an Ar-gas atmosphere. Theirs transparent products have 90% in-line optical transmittance at 300-5000nm, 250 MPa in fracture strength and 2.8 $MPa.m^{1/2}$ in fracture toughness.

2.2 Methodologies for development of the alumina green body with high density

To give the sintered body with high density and small size of grains, the green body density must be high in order to decrease the sintering condition significantly affected to the growth of grains. This reviews investigated on some of techniques that use to develop the properties of green body specimen as follow;

X. Li et al. (2003) employed centrifugal slip casting technique on preparation the green bodies of two different alumina powders. The coarse powder (UE-3081) has average grain size of 0.5μm whereas the fine powder (TM-D) has average grain size of 0.2 μm. They found that preparing fine powder consume more amount of dispersant for the maximum solids loading of TM-D and UE-3081 prepared for consolidation are 44 and 59.8 % vol., respectively conform to the amount.

J. Davies et al (2000) investigated the role of deflocculant such ammonium polyacrylate in dispersing concentrated alumina suspension. Due to degree of suspension dispersion can be measured by suspension viscosity. They investigated on that parameter combined with the absorption of deflocculant on the alumina surface. They found that the more stable of alumina suspension can be obtained by using the suitable concentration of deflocculant that provided the second minimum absorption on the surface.

J. C. Kim et al. (1999) investigated the effects of adding polysaccharides having various concentrations and molecular weights (M.W.) on the consolidation behaviors of alumina suspension. Polysaccharides are not only steric-hindering media which were provided the creation of a steric adlayer that inhibits the close contact of individual particles, but also binder which were provided more strength to green body alumina. From their experiments, they found that green densities of alumina specimens which were casting from suspension with 20 vol% solid loading and low M.W. of polysaccharide were not increased, meanwhile, adding high M.W. with the suitable concentration were provides higher green densities than the lower one. Furthermore, specimen with less than 9500 M.W. of polysaccharide showed green tensile strength about 2-5 times higher than specimens without polysaccharide as well as in case of adding 950 M.W. showed the tensile strength about 10 times.

G. Tari et al (1998) prepared blended two types of commercial powder (Alcoa Chemicals, USA) having different average particle size with polyacrylic acid as deflocculant formed by slip casting. "A16" is the finer powder and "CT530" is the

coarser powder. They founded that the change in proportion between coarse and fine particles and a decrease in particle size ratio of coarse powders to fine powders are factors responsible for a decrease in green body density.

Y. Hashi et al. investigated the effects of addition timing of dispersant on the slurry viscosity and properties of slip cast bodies. They found that adding of dispersant during grinding was more effective in decreasing the viscosity of slurries and in increasing the density of slip cast bodies than adding after grinding.

J. Cesarano III et al. (1988) investigated the stability and rheology of alumina suspensions with polymethacrylic acid and polyacrylic acid polyelectrolytes as function of pH, solid loading, and molecular weight.

C. Guler et al. (1998) investigated the effect of cation and anion salt and anion salt on the viscosity of clay slurries. The clay particles have a negative surface charge which has a capacity to attract and absorbed cations from the surrounding suspension. They found that the flocculated suspensions are occurred in the presence of high valence cations such as Ca^{2+}, Fe^{2+} and Mg^{2+}, and of the anions such as SO_4^{2-} and Cl^-.

B. J. Briscoe et al. (1998) investigated the behavior of the ammonium polymethacrylate (Dervan C), aurintricarboxylic acid ammonium salt (Aluminon) and 4-5-dihydroxy-1, 3-benzenedisulfuric acid disodium salt (Tiron) on the stability of the alumina suspension. They found that Aluminon and Tiron that the ring structure provide the higher efficiency to stabilize the alumina suspension than the Dervan C.

S. Sumita et al (1991) investigated the effect of the organic dispersant on green body and sintered body properties. They found that density of green body was dependent primarily on the concentration of dispersants rather than pH which were taken further effect via green body microstructure, density and microstructure of sintered body.

2.3 Influence of impurities on the properties and microstructure changes in the alumina sintered body

Beside the appropriated process for obtaining the green body with highest density, the impurities of specimen must be significantly emphasized. The section of report focused on what kinds of and how impurities that take the bad effect to specimens after final stage sintering.

N. Louet et al. (2005) investigated the effects of the relative amount s of the impurities such as NaO_2 and SiO_2 that normal encountered in commercial powder obtained by Bayer process. They found that an increase in Na_2O content significantly slows down the densification and slightly slows down the grain growth. In contrary, the addition of SiO_2 does not affect significantly the final density but leads to abnormal grin growth and increases the aspect ration of grains.

H. Yoshida et al. (2005) monitored on the densification behavior of the alumina doped with various cations of Mg, Mn, Sr, Lu, Ti, Zr and Pt. They found that the grain boundary diffusivity is sensitively affected by the doped cation which segregates at the grain boundaries. The dopant effect on the grain boundary diffusivity is related to the ionicity in Al_2O_3. A lower energy level of the dopant element's outer shells provides a high value of diffusivity in the divalent or tetravalent cation-doped alumina.

S. H. Hong et al. (2001) investigated the microstructure evolution of alumina ceramic prepared by adding small amounts of CaO and TiO_2 that become a liquid phase during sintering. They found that a duplex microstructure of a few abnormal grains and fine matrix grains were observed when the CaO + TiO_2 content was small ($\leq$ 0.04 wt%). Meanwhile, adding of relatively high CaO + TiO_2 ($\geq$ 0.1 wt%) provided many growth of grains that impinged upon each other.

S. J. Cho et al. (2001) examined the effect of the coarsed-powder portion on the abnormal grain growth occurrence in commercial-purity alumina. They found that adding of coarse alumina powder which has high impurity in MgO-doped high purity alumina significantly leads to extensive abnormal grain growth occurrence.

2.4 Development of sintering technique

C. Nivot et al. (2006) investigated on the effect of nitrogen pressure on the densification of fine grained pure alumina during temperature between 1150-1650 ^{o}C and pressure during 0.1-6 MPa. They found that increasing of pressure on sintering significantly reduces the density of alumina products during the initial and intermediate stage of sintering, whereas, the average diameter of grains was decreased about 20-25%. Moreover, they also observed on microstructure evolution as a function of relative density. According to their experiment, they can conclude that the grain growth does not occur up to 80% relative density. On contrary, they were abruptly increased at over 85% relative density for any pressure applied.

M. Wakamatsu et al. (1991) investigated on the sintering atmosphere effect on the properties of the vanadium-doped alumina ceramic. They found that the properties of sintered specimen with oxidizing and reducing atmosphere are different.The of vanadium in oxidizing state was present preferentially between alumina grains, forming a $AlVO_4$ phase, help to depress both densification and grain growth, provide low flexural strength and hardness. In contrast, in the reducing atmosphere, vanadium is prefer to dissolved in alumina asV^{3+} and slightly present as V^{+4} at the grain-boundary region, help only to depress the grain growth and provide comparatively high hardness.